

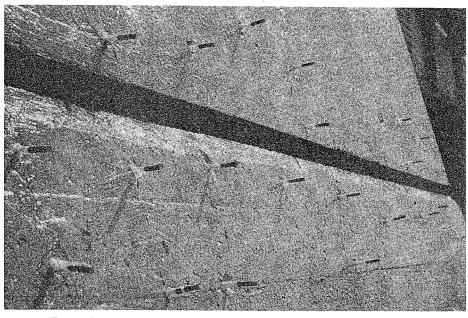
The REMR Bulletin

News from the Repair, Evaluation, Maintenance, and Rehabilitation Research Program

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MAY 1989



Ports in gate pier for pressure injection repair, Dam 13, Mississippi River

In Situ Repair of Deteriorated Concrete

by
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US Army Engineer Waterways Experiment Station

Repair of concrete in hydraulic structures generally involves removing the deteriorated concrete and replacing it with new, cast-in-place concrete. To develop alternatives to concrete removal and replacement, a study was initiated, as part of the *REMR* Research Program, to evaluate in situ repair procedures. This study was conducted by Brookhaven National Laboratory (BNL) through a Support Agreement with the US Army Engineer Waterways Experiment Station.

The initial step in this effort was a feasibility study to identify both the

types of deterioration most prevalent in concrete hydraulic structures and the existing materials and methods commonly used for repair and rehabilitation. Once this information was collected, it was evaluated to determine the applicability of the various systems to the in situ repair of concrete hydraulic structures.* Of the repair

^{*} Webster, R. P. and Kukacka, L. E. 1987 (May). "In Situ Repair of Deteriorated Concrete in Hydraulic Structures: Laboratory Study," Technical Report REMR-CS-6, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

techniques identified as being applicable to in situ repair, the pressure injection technique was selected for detailed laboratory evaluation. This procedure has been used extensively for repair of single, continuous cracks in structural concrete, but experience in pressure injection of mass concrete containing an internal network of multiple, interconnecting cracks has been minimal.

LABORATORY TESTS

Eight injection adhesives were experimentally evaluated to determine their effectiveness in the repair of cracks in air-dried and water-saturated concrete. The adhesives were three epoxies, an emulsifiable polyester resin, furfuryl alcohol, a furan resin, a high molecular weight (HMW) methacrylate, and a polyurethane. Slant shear bond strength tests (ASTM C 882) were used in the initial evaluation of the adhesives. Because of their low bond strength to water-saturated concrete, the furan resin, furfuryl alcohol, and the polyurethane were not considered further as injection adhesives. The remaining adhesives were used to repair both air-dried and water-saturated concrete slabs by injection. Slab dimensions were 18 by 18 by 3-1/2 in. thick; crack widths at the surface ranged up to 5 mm. The injection procedure used to repair the slabs was as follows: (a) sandblast concrete surface, (b) clean cracks, (c) attach injection ports, (d) seal the concrete surface, and (e) inject cracks (Figure 1).

The effectiveness of the repairs was evaluated by ultrasonic pulse velocity measurements before and after injection, visual examination of cores removed from each slab, and splitting tensile strength tests on the cores. Results of these evaluations indicated that each of the adhesives can restore the structural integrity of concrete containing air-dried and water-saturated cracks. However, the most promising adhesive was Denepox 40, a two-component, very low viscosity epoxy system designed specifically for pressure injection repairs.* Slabs with both types of cracks repaired by injection with this epoxy had ultrasonic pulse velocities varying from 14,000 to 15,000 fps as compared with preinjection pulse velocities of 7,120 to 12,110 fps. Good quality concrete normally has a pulse velocity of 14,000 to 15,000 fps. The

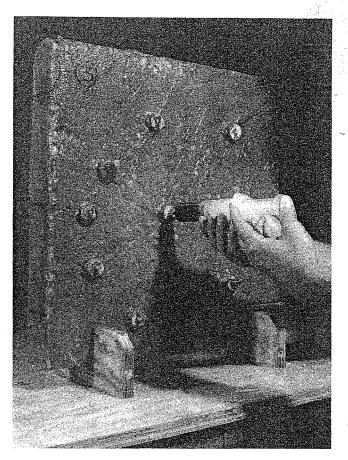


Figure 1. Laboratory injection of cracked concrete slab

splitting tensile strength of the repaired concrete was equal to or greater than that of the control concrete.

Once the adhesive was selected, the next step was to optimize the repair procedures and to evaluate equipment to be used in the small-scale field test. This step was accomplished by pressure injection of three 8-ft, 4-in.-high by 5-ft, 4-in.-wide by 3-ft-thick concrete shielding blocks and a 15-ft-high concrete retaining wall. Maximum crack widths at the surface were approximately 0.039 in.

After the shielding blocks were injected with epoxy, the average ultrasonic pulse velocity (11,230 fps) was approximately 17 percent higher than the preinjection velocities. A visual examination of the 15 cores removed from the block revealed that the cracks extended to depths of 3.5 to 3.9 in. With the exception of several cracks in two cores, all of the cracks appeared to be completely filled with epoxy. Results of splitting tensile strength tests ranged from 340 to 815 psi and averaged 610 psi, compared with 545 psi for the control.

^{*} Webster, R. P. and Kukacka, L. E. 1988 (Jan.) "In Situ Repair of Deteriorated Concrete in Hydraulic Structures: Laboratory Study," Technical Report REMR-CS-11, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

After the retaining wall was injected, the average ultrasonic pulse velocity (13,180 fps) was approximately 45 percent higher than preinjection velocities measured across the crack. Visual examination of cores removed from the wall after repair revealed that the crack extended a minimum of 12 in. into the wall and was 80 to 100 percent filled with epoxy.

FIELD TEST

A field test was performed on a tainter gate pier stem at Dam No. 20, Mississippi River. The objectives of the field test were to demonstrate, under actual field conditions, the procedures developed in the laboratory and to evaluate the effectiveness of the materials and equipment selected for use.*

The repair work was limited to the top 4.2 ft of the pier stem, the area above the archway ceiling of the walk-through. The deterioration in this area was characterized by two major cracks that extended from the top of the pier stem down to the ceiling of the archway. Also, a network of cracks was visible on the upstream and downstream faces of the pier stem. The procedure developed in the laboratory was used to inject approximately 5 gal of epoxy into the top of the pier stem over a period of 2 days (Figure 2).



Figure 2. Small-scale field test at Dam No. 20, Mississippi River

Approximately 3 weeks after injection, seven 4-in.-diam cores and one 6-in.-diam core were removed from Pier 27. Three of the cores tested by the Rock Island District averaged 6,630 psi and 12,055 fps, compressive strength and ultrasonic pulse velocity, respectively. A fourth core was examined petrographically.

The four remaining cores were sent to BNL for testing. In addition, a section of core that contained no visible cracks was furnished. A visual examination of the four complete cores showed that the crack network in three of the cores was 80 to 90 percent filled with epoxy, and the cracks in the remaining core appeared to contain no epoxy. Test results are summarized in the following:

Concrete	Pulse	Splitting Tensile
Condition	Velocity, fps	Strength, psi
Uncracked	13,990	550
Cracked*	7,165	345
Repaired**	11,760	515

^{*} No apparent epoxy.

Freeze-thaw testing was done on three of the cores, two with partially filled cracks and a third that appeared to contain no epoxy in the cracks. The cores were subjected to a total of 100 cycles of freezing and thawing in accordance with ASTM C 666, Procedure A. Ultrasonic pulse velocity data were taken throughout the duration of the test. The pulse velocities of the cores with partially filled cracks decreased approximately 26 percent, while the pulse velocity of the core with no visible epoxy decreased about 64 percent.

Tests conducted on discs cut from two cores with partially filled cracks indicated that the average splitting tensile strength had decreased from 565 to 390 psi after 100 cycles of freezing and thawing. The splitting tensile strength of the core with no visible epoxy had decreased from 345 to 80 psi after 100 cycles.

In spite of the reductions in the pulse velocities and splitting tensile strengths of the cores with partially filled cracks, the concrete appeared to be in good condition, with only minor surface scaling and no deterioration around cracks. In comparison, the core with no visible epoxy exhibited severe deterioration in the form of cracking, aggregate popouts, and erosion of the cement paste. Contrary to the initial belief that this core contained no

^{*} Webster, R. P., Kukacka, L. E., and Elling, D. (In publication). "In Situ Repair of Deteriorated Concrete in Hydraulic Structures, A Field Study," Technical Report REMR-CS-21, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

^{** 80-90} percent of cracks filled.

epoxy, an examination of the interior of the core after testing indicated that some of the cracks contained 20 to 30 percent epoxy; this fact helps explain how the core, which was nonair entrained and highly cracked, withstood so many cycles of freezing and thawing.

LARGE-SCALE FIELD TEST

Problem areas identified during the initial field test were addressed through additional laboratory evaluation. These areas include:

- Developing a better method for attaching the injection ports to the concrete.
- Evaluating the need to drill into the crack network to facilitate epoxy penetration.
- Evaluating additional materials for use as sealants.
- Repairing and modifying the field injection equipment.

The product of this laboratory work was a modified repair procedure which was demonstrated at Dam No. 13 on the Mississippi River near Fulton, Illinois. The upper 10 ft of one pier had suffered extensive cracking (Figure 3) as a result of cycles of freezing and thawing and alkali-aggregate reaction. Crack widths varied from less than 0.03 in. to 0.5 in. Cores taken from the pier indicated that the cracking extended approximately 6 to 12 in. into the face of the pier (Figure 4).

Prior to the repair, BNL took 30 pulse velocity readings from various locations around the pier. The results indicated that the quality of concrete in the pier was extremely poor.

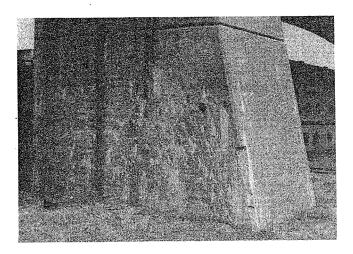


Figure 3. Concrete surface condition of pier at Dam No. 13 on the Mississippi River



Figure 4. Typical concrete core prior to pier injection

The first step in the repair procedure was to sandblast the pier. Next, approximately 800 1/2-in.-diam port holes were drilled to a depth of 6 in. These holes were wet drilled to flush fines from the holes as they occurred. After injection ports were installed, the entire surface of the pier was sealed with Deltapox VM (Figure 5), a two-component epoxy designed for use in vertical and overhead applications. The seal was cured for approximately 1 day before injection was begun.

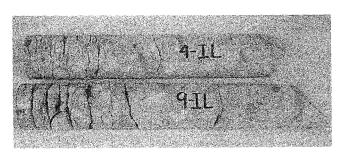


Figure 5. Sealing the entire surface with epoxy after injection ports were installed

A modified manifold system that allowed injection through three ports simultaneously was used to inject approximately 62 gal of Denepox 40 epoxy into the pier over a 4-day period. Postinjection pulse velocity measurements were taken approximately 18 hr after injection was completed. Average results of pulse velocity measurements are summarized below:

	Average Ultrasonic	Pulse Velocity, fps
Location	Preinjection	Postinjection
Between the faces	1,500	4,075
Corners of the piers	2,675	11,720
Through parapet walls	6,070	9,680

After completing the in situ ultrasonic pulse velocity measurements, personnel from the Rock Island District removed five 4-in.-diam cores from the pier. A visual examination of cores taken before and after injection (Figure 6) indicated that the injection procedure worked very well and the repair was considered a success. Laboratory test results substantiated this conclusion. For example, splitting tensile strength of the repaired cores was more than twice that of the unrepaired cores and was only 10 percent less than the strength of the uncracked concrete. Therefore, in situ repair of gate piers seems to be a viable alternative to conventional concrete removal and replacement.



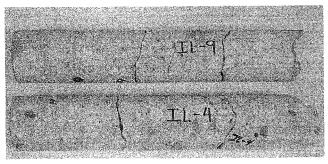


Figure 6. Typical cores before (top) and after injection

APPLICATION

As a result of this work, the Rock Island District has decided to use pressure injection for rehabilitation of 38 tainter gate piers at Dam No. 20. Instead of removing and replacing 11 ft of the pier stems as originially planned, current plans are to remove only the top 1.5 ft and inject the remainder. This removal is being done to allow replacement of the service bridge seats and to improve drainage on top of the piers. Savings as a result of this change are estimated to range from \$350,000 to more than \$1 million.

For further information, contact Jim McDonald at (601) 634-3230.

James E. McDonald is a research civil engineer in the Concrete Technology Division, Struc-Laboratory,WaterwaysExperiment Station. He is problem area leader for the Concrete and Steel Structures portion of REMR and is also principal investigator for four REMR work units, including 32308, "In Situ Repair of Deteriorated Concrete." He has been involved with various aspects of concrete research for 28 years. McDonald received his B.S. and M.S. degrees in civil engineering from Mississippi State University.



Rehabilitation of Crow Dam Gate Tower

by
Robert V. Todd
Bureau of Reclamation, Denver, Colorado

Crow Dam, located approximately 7 miles southeast of Ronan, Montana, was completed in 1933. The dam is owned by the Bureau of Indian Affairs (BIA) and operated by the Flathead Irrigation and Power Project in St. Ingnatius, Montana. The outlet works, which are adjacent to the left abutment of the dam, consist of a concrete intake structure with trashracks, a transition to a concrete pressure tunnel, a hand-operated butterfly valve, a concrete gate tower and annulus, a downstream tunnel containing a gooseneck, and a concrete stilling basin (Figure 1).

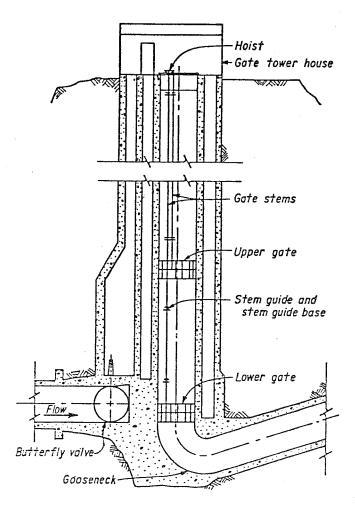


Figure 1. Gate tower

The shaft of the concrete gate tower is 94 ft high; it contains two 6-ft-diam by 3-ft-high castiron cylinder gates, which are used for making releases for irrigation. One gate is located at the bottom of the tower; the other is 24 ft higher. Normal water demand requires only one gate to be partially opened. At partial openings, fluctuating hydraulic loads act on the bottom of the gates and through the gate stems to the top of the gate tower. The mechanical structures respond dynamically like a large mass on a soft spring. Resulting displacements of the gates and stems under fluctuating loads have caused failures of the gates, stems, and guides.

During failure, guide brackets for the gates either break off completely, or the bolts holding them break. The extra radial displacement is then transferred to the first stem guides above the gates. These stem guides crack, and the bolts holding the stem guide base to the concrete wall break; this process continues until finally the stems themselves fail. Then the gates fall onto the seat rings and sustain additional damage. This scenario took place at Crow Dam in 1980 (Murth 1980).

With the three sets of stem guide bases for the lower gate broken away from the gate tower wall and the stems broken, engineers decided to hang the lower gate from cables attached to the undamaged stems 42.5 ft above the gate. After only one season of operation, the cables broke, and the lower cylinder gate shell structure sustained cracks (Elliott 1982). Releases from the gate tower were then possible only through the upper gate. In 1984, the lower cylinder gate was removed, and the open ports in the gate casing were blocked with steel plates (Ingram 1985). In addition to the damage to the gates and stems, the concrete below each gate sill had been eroded, and the embedded reinforcing bar in the gooseneck concrete section was exposed for several feet.

REHABILITATION PROGRAM

Because of the overall deterioration of the gate tower and the associated mechanical equipment, a rehabilitation program was required. Three criteria determined the extent of the rehabilitation work:

- Urgency if the upper gate malfunctioned, there would be no means of making controlled releases from the outlet works.
- Finance the \$600,000 allocation from the safety of dams program for design and construction had to cover the cost of a new spillway as well.
- Opportunity the work would have to be performed during one winter shutdown period to be completed before the following spring runoff and irrigation season.

Two rehabilitation options were considered: (a) replacement of the cylinder gates with slide gates and (b) reconstruction of the cylinder gate system and restoration of the damaged areas of the gate tower. The latter option most closely met the criteria. Because of limited funding, BIA decided to use its own work force to do the rehabilitation work but requested that the US Bureau of Reclamation (USBR) administer the contract and provide technical assistance in preparing specifications.

CASTING VERSUS WELDMENT

The original cylinder gates, guide brackets, stem guides, and stem guide bases were made of gray cast iron. Initially, the decision was to replace these parts with castings similar to the original ones. However, when the specifications were put out for bids in 1985, there was no response. The specifications were then amended to give the contractor the option of using weldments or castings (Solicitation No. 7-SP-10-08320, 1986). This change resulted in a number of bids, all quoting the weldment option.

In changing the method of fabrication from a casting to a weldment, BIA had to compensate for the inherent fatigue proneness of a welded structure. A low carbon steel, ASTM A36, was used to make the weldments. It is very ductile and has low notch sensitiveness and is, therefore, a good material for a low stress-fatigue application. It has a minimum ultimate strength of 58 ksi (400 MPa). Because of the strength of the steel, the thicknesses of the gate components could have been reduced; however, taking fatigue into consideration nullified the strength advantage, and no change in any component thicknesses was made. To ensure structural integrity of the weldments,

workers x-rayed all critical welds and kept fillet welding to a minimum.

MATERIAL CHANGES

The original material for the seating rings for the cylinder gates was cast manganese bronze. This material is no longer commercially available in this form, and the cost to fabricate it would be prohibitive. Therefore, the material for the seating rings was changed to centrifugally cast aluminum bronze, which has the necessary characteristics and is commercially available and reasonably priced. All of the bolts were changed from low carbon steel to stainless steel. This change was made to obtain the superior anticorrosion properties of stainless steel.

ADJUSTMENT OF SEAT RINGS

Originally, the cylinder gate casing was a onepiece casting. When the seat rings were installed, the gate could be lowered into the gate casing, a water-tightness test could be performed, and the seats could be machined or ground until leakage requirements were met. However, in the case of the replacement gates, making modifications in the field was not practical. To ensure that contact necessary for water tightness could be obtained in the field installation, a test fixture with the same inside profile as the gate casing was specified. The new casing seat rings were installed in the test fixture, the cylinder lower seat was positioned on one of the gate cylinders, and the cylinder upper-seat ring was emplaced on the gate cylinder with the clamping ring allowed to float one quarter of an inch. The gate was then lowered into the test fixture so that both sets of gate seat rings made line contact with the casing seat rings.

To obtain the field adjustment of the upperseat ring, five 1-in.-diam holes were drilled in each of the three clamping rings, between the existing holes, to coincide with the inside face of the cylinder upper seat ring and the gate cylinder. During installation of the gates, the lower gate, with its cylinder bottom seat ring installed, was lowered down the tower so that the gate seated on the bottom casing seat ring. The cylinder upper seat ring was then placed in position, and the clamping rings were installed with shims located between the clamping rings and the top of the gate to maintain a maximum gap of 0.020 in. at location "A" in Figure 2.

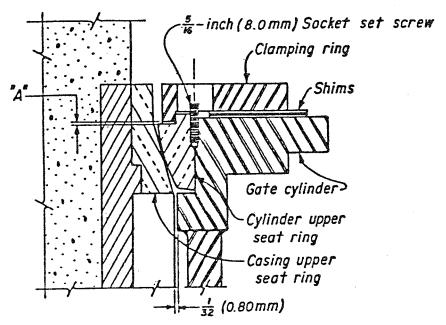
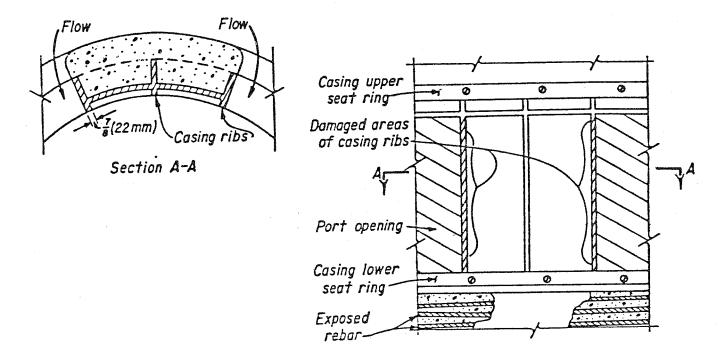


Figure 2. Upper seating adjustment

Holes were drilled and tapped for socket set screws at the locations of the 1-in. holes in the clamping rings. The shims were then adjusted so that the clamping ring firmly held the seat ring. This procedure ensured that if the lower seat rings were to lose contact after a period of time, the gate weight would not be solely on the set screws.

MOLECULAR WELDING REPAIR SYSTEM

Both upper- and lower-gate casings had damage on the inside surfaces of the vertical ribs (Figure 3). The casing ribs adjacent to the port openings had suffered from erosion, and the fluctuating



NOTE: Gate not shown.

Figure 3. Gate casing damage

radial movement of the gate at different openings had caused the casing ribs to break away. Because the gate casing is embedded in concrete, the cost of replacing it would have been extremely high. Also, because the casing is made of cast iron, repairing it with conventional welding techniques would have been difficult. However, molecular welding, a modern technology that uses proprietary materials to build up damaged metallic areas, can be used to repair the type of casing damage found at Crow Dam. A base and solidifier mixed together to form a compound that has nonslump, nonshrink characteristics and a short curing time is ideal for field applications in which access and working conditions are confining and awkward. Once cured, the material has the mechanical properties of a low carbon steel and can be machined or ground for final sizing.

Steps involved in the repair included: brushing away any loose contaminates, grit-blasting with copper slag, mixing and applying Belzona Molecular Ceramic R-Metal,* curing for 2 hours, measuring and reapplying the repair material until the build-up was satisfactory, and finally brush coating with 10 to 15 thousandths of Belzona Molecular Ceramic S-Metal* to give added protection against erosion and corrosion.

CONCRETE REPAIRS

The damaged areas on the inner surface of the gate tower were repaired with epoxy mortar. The badly damaged area of the gooseneck that had exposed reinforcing bars was fitted with a steel liner and backfilled with concrete. Areas around the casings where bonding was required were repaired with Belzona Molecular Magna-Quartz,* a polymeric alloy consisting of organic molecular compounds and inorganic micronized magna-quartz, because of its long lasting adhesion properties. Each micronized quartz particle is pre-encapsulated with a monomolecular layer of surface-active agents to ensure a homogeneous mixture with no intercrystalline weak points. It cures within 12 hr. Areas to be repaired were cleaned, dried, brush treated with a surface conditioner, filled with magna-quartz, and then leveled with a trowel.

FIELD INSTALLATION OF GATES

The field installation of the gates, stems, and guide brackets was accomplished during the winter of 1987-88. Because of the minimal clearances between the gates and the casings, considerable localized grinding of the repaired casing ribs had to be done. This experience proved that it would have been advantageous to have had a template of the outside profile of the gate for checking clearances between gate and casing.

The BIA has two more projects with gate towers that have identical gates to those at Crow Dam. When these gate towers need rehabilitating, the experience obtained from performing the work at Crow Dam will be invaluable, not only from the standpoint of cost and materials tracking but also because of the identification of problem areas and solutions.

CONCLUSIONS

The rehabilitation work performed on the gate tower at Crow Dam highlighted a number of areas that should be considered when an old structure needs to be rehabilitated:

- Manufacturing processes change with time, and improved technologies make some processes obsolete or no longer cost-effective.
- The availability and types of materials also change with time; procuring materials called for in the original design may not be possible.
- Original methods of obtaining certain operational requirements may not be practical under the rehabilitation conditions.
- Repairing materials and equipment instead of replacing them may be practical and considerably less expensive.

For further information, contact Robert V. Todd at US Department of the Interior, Bureau of Reclamation, P. O. Box 25007, Attention: D-3422, Denver, Colorado 80225-0007.

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^{*} These were products used on the rehabilitation work; however, the Bureau of Reclamation does not endorse these products over similar products by other manufacturers.

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Robert V. Todd, Mechanical Branch, USBR, has worked 11 years for the Bureau of Reclamation at the Denver Office as a mechanical engineer specialist. His speciality is fluid-structure dynamic problems and analyzing complex structures. Prior to coming to the Bureau, Todd worked 16 years in the aerospace industry as a designer/stress analyst.



REMR Technology Transfer Symposium Scheduled

A symposium to share information on innovative technology for the maintenance, repair, and rehabilitation of structures takes place Sept. 7 and 8, 1989, in the Minneapolis/St. Paul area.

According to William F. (Bill) McCleese, *REMR* program manager, the use of technology developed during the 6-year research program for Repair, Evaluation, Maintenance and Rehabilitation of Corps Civil Works structures has already saved millions of dollars. To realize all the potential benefits of the program, *REMR* technology must be used whenever it can be applied. "Almost any Corps project can

benefit from this technology." said McCleese.

Fiscal Year 89 is the final year of funding for the *REMR* program. The symposium marks the end of most of the research units.

"Technology transfer of these research results will be the main thrust at the symposium," McCleese said. "We'll offer the opportunity to learn about application in all work areas. I'm hoping that in addition to our regular attendees a lot of division chiefs from Corps Divisions and Districts will block this date on their calendar and attend," he added.

Details will be published later.

Video Report Added to REMR Publications

A video report entitled "Antiwashout Admixtures for Use in Underwater Concrete Placement," has recently been completed. Principal Investigator is Kenneth Saucier. Billy Neeley is the author.

The report is 15 minutes and 20 seconds long, and is available on 1/2-in. cassette on inter-library loan from the Waterways Experi-Station Library, telephone (601) 634-2355. The report number is Video Report REMR-CS-3.

This information has been available from REMRNET since March 17, 1989.

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COVER PHOTOS

Dam No. 20, Mississippi River, injection port installation. Crow Dam, Montana gate tower.



The REMR Bulletin

The REMR Bulletin is published in accordance with AR 310-2 as one of the information exchange functions of the Corps of Engineers. It is primarily intended to be a forum whereby information on repair, evaluation, maintenance, and rehabilitation work done or managed by Corps field offices can be rapidly and widely disseminated to other Corps offices, other US Government agencies, and the engineering community in general. Contributions of articles, news, reviews, notices, and other pertinent types of information are solicited from all sources and will be considered for publication so long as they are relevant to REMR activities. Special consideration will be given to reports of Corps field experience in repair and maintenance of civil works projects. In considering the application of technology described herein, the reader should note that the purpose of *The REMR Bulletin* is information exchange and not the promulgation of Corps policy; thus, guidance on recommended practice in any given area should be sought through appropriate channels or in other documents. The contents of this bulletin are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products. The REMR Bulletin will be issued on an irregular basis as dictated by the quantity and importance of information available for dissemination. Communications are welcomed and should be made by writing the Commander and Director, US Army Engineer Waterways Experiment Station, ATTN: Bill McCleese (CEWES-SC-A), PO Box 631, Vicksburg, MS 39181-0631, or calling 601-634-2587.

> JACK R. STEPHENS LTC. Corps of Engineers Acting Commander and Director

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